547

VOLUME 80 SEPARATE No. 547

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

NOVEMBER, 1954

ARTIFICIAL PRECIPITATION CONTROL

by Ray K. Linsley, M. ASCE

SANITARY ENGINEERING DIVISION

(Discussion open until March 1, 1955)

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

THIS PAPER

--represents an effort by the Society to deliver technical data direct from the author to the reader with the greatest possible speed. To this end, it has had none of the usual editing required in more formal publication procedures.

Readers are invited to submit discussion applying to current papers. For this paper the final date on which a discussion should reach the Manager of Technical Publications appears on the front cover.

Those who are planning papers or discussions for "Proceedings" will expedite Division and Committee action measurably by first studying "Publication Procedure for Technical Papers" (Proceedings – Separate No. 290). For free copies of this Separate—describing style, content, and format—address the Manager, Technical Publications, ASCE.

This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

ARTIFICIAL PRECIPITATION CONTROL

Ray K. Linsley,[1] M. ASCE

SYNOPSIS

The possibility that man has learned to control and augment natural precipitation is intriguing to the engineer engaged in water supply and other hydraulic work. Such an advance would almost certainly lead to major changes in hydraulic design practices. This paper surveys the theory and present status of precipitation control, so that engineers may evaluate the present possibilities in this field of meteorology.

INTRODUCTION

The world's reserve of fresh water is a tiny portion of the total water on the earth, and it would be totally inadequate to sustain human life if it were not replenished by precipitation. Solar energy provides heat to distill the salt water of the oceans and creates winds which carry the resulting vapor over the continents. A portion of the vapor passing over the land masses of the world is condensed and falls as rain or snow to provide the fresh water man needs for existence. No practical method is yet available by which man can separate the dissolved salts from sea water to produce potable water on a large scale at a reasonable cost. Perhaps atomic energy is a possible source of the necessary power. It has been estimated that conpression-distillation of sea water[2] would require about as much fuel per capita as is now required for electric power generation in thermal power plants.

Unfortunately the natural delivery of fresh water to the land areas of the earth is very erratic. Often a quantity far in excess of local needs is delivered in a short period of time and is largely wasted to the sea as flood water. In contrast, long periods of time may elapse with little or no significant precipitation in some area. Large areas of land never receive enough precipitation to sustain a population without artificial aid. Man has learned to store water in reservoirs so that he will have a reserve supply for use when precipitation is inadequate. An increasing demand for water accentuated by a severe drought has often found such reserve supplies inadequate. There is little doubt that many early civilizations collapsed under the pressure of long-sustained droughts. Few people appreciate the seriousness of the problem more fully than the engineers responsible for the design and operation of water supply, irrigation, and hydroelectric power systems.

The thought of increasing water supplies by increasing the precipitation is a tempting one. It is the only conceivable means of immediate relief during severe droughts. Even though a water shortage is not imminent, the possibility of obtaining more water without the problems or cost of additional reservoirs or collection systems is tempting. If it were possible to substantially increase precipitation in the arid regions of the world, large land areas could

1. Assoc. Prof. of Hydr. Eng., Stanford Univ., Stanford, Calif.
2. "Fresh Water from Salt Water," by Everett D. Howe, Trans. Amer. Geophys. Union, Vol. 33, p. 420, June, 1952.

be put to profitable use without any elaborate scheme for transfer of water from areas of more favorable natural supply. It is hardly surprising that early man implored his deities to bring rain or attempted to placate the "evil spirits" which were obstructing the good intentions of the gods. Since the advent of the industrial revolution and modern science, man has explored freely the possibilities of increasing rainfall through use of such "scientific" measures as cannon fire into the clouds, steam generators, chemical smokes, and many secret devices. Professional rainmakers were very active during the 19th century and the early years of the 20th century, but few are to be found today.

Subsequent to World War II, efforts at precipitation control have been renewed with the support of eminent scientists. Methods have been developed which have a foundation in accepted theories of rain formation. The modern approach to rainmaking is plausible, and has been demonstrated to be successful to the point where it cannot be dismissed lightly. There is little doubt that cloud-seeding has caused precipitation which would not have occurred naturally. It remains to be demonstrated that the process can induce precipitation in quantities which have economic value at a time and place where rain is needed.

The first known effort at seeding clouds with dry ice from an aircraft was in 1931 by a Dutchman, August Veraart. It appears that Veraart was at least modestly successful in his trials, but he could not overcome the scoffing of his colleagues and died before his success was acknowledged. We know that Veraart's theory for the process he employed was not in accord with our understanding of the phenomenon today.

Causes of Precipitation

Water vapor is always present in the atmosphere in amounts varying up to a maximum of about four per cent. The condensation of this vapor to liquid form results when the air is cooled below its dewpoint temperature. Cooling of the air from below, as when warm air moves over cold ground, snow, or water, cause the air near the surface to become relatively more dense than air at higher levels. This creates a stable equilibrium, i.e., convection currents are suppressed and the cooling does not extend to very great heights. Condensation caused by cooling from below usually results only in dew, frost, or shallow ground fog. The only effective means of cooling large air masses is by lifting them to a region of lower pressure. Here the air expands and cools in accordance with the gas laws. Lifting may occur as a result of air being forced up over a mountain range (orographic lifting), by warm air rising over colder air (frontal lifting), or by heating from below which sets up convection currents (convective lifting). Orographic lifting is an important cause of precipitation in mountainous areas, but in the plains region frontal lifting is the main cause of widespread storms. Convective lifting is responsible for summer thunderstorms. Often two or three of the lifting mechanisms function together.

If the air which is lifted has a relative humidity less than 100 per cent, it cools at a rate of about 5 F° for each 1000 feet that it is raised, until its temperature is lowered to the dewpoint temperature. At this level the air is saturated with water vapor and droplets of liquid water appear to form a cloud. The elevation of the cloud bases thus marks the condensation level. The condensation process releases the latent heat of vaporization of the water and this reduces the cooling rate as the air is lifted above the condensation level to about 3 F° per 1000 feet of lift.

The tiny water droplets formed by condensation average only about 0.01 mm (0.0004 in.) in diameter. Some 10,000 such drops could be nested on the head of a common pin. Droplets this small are easily supported in the air by very slight upward air currents. This condition is observed in fog where the drops seem to hang suspended in the air. Even if the drops do fall out of the cloud they will evaporate before they have fallen more than a few feet through the unsaturated air below the cloud base. Thus, before any appreciable amount of precipitation can occur the cloud droplets must grow to a size sufficient to permit them to reach the ground. Since the weight of a sphere increases as the cube of its diameter while its projected area increases only as the square of the diameter, it is possible for the drop to reach a size at which the increased weight overcomes the resistance of upward air currents. The smallest raindrops observed in heavy rain are in the order of 0.5 mm (0.02 in.) in diameter while the average size of raindrops is in the vicinity of 1 mm in diameter. An increase in diameter from 0.01 mm to 0.5 mm involves an increase in mass of 125,000 times.

The mechanism which brings about the growth of cloud droplets to precipitation elements is still very imperfectly understood. An early theory suggested that coalesence resulted from the mutual attraction of drops with unlike electrical charges. Because of the small charge carried by cloud drops and the realtively large distances between the drops, electrical attraction does not appear to offer a very effective mechanism for coalesence. Moreover, coalesence would neutralize the charges on the drops and bring the process to a fairly abrupt end. It seems more plausible that the existence of unipolar charges is a factor in preventing coalesence in some cases. Another theory suggested that coalesence might result from the movement of vapor from a drop having a high vapor pressure to one with a lower vapor pressure. Differences in vapor pressure might result from differences in drop temperature (warm drops would evaporate and condense on colder drops) and differences in drop size (small drops would evaporate and condense on larger drops). Large differences in temperature between adjacent cloud elements are not likely to occur and it has been shown that the effect of differences in drop size is quite small[3]. Thus, it must be concluded that these two effects cannot contribute in any large measure to coalesence of cloud elements.

In 1935 Bergeron suggested that the difference in vapor pressure between ice and water at the same temperature was sufficient to explain the evaporation of water drops and the condensation of the vapor on the ice crystals[4]. Thus the coexistence of water droplets and ice crystals in a cloud might provide a mechanism for the formation of precipitation elements. It is often observed that rain does not occur from thunderclouds in the middle latitudes until the top of the cloud shows a diffused, fibrous appearance characteristic of ice crystal clouds. This lends considerable support to the Bergeron ice-crystal theory of raindrop formation. However, heavy rain frequently occurs in the tropics from clouds which do not contain ice crystals and moderate rain has been observed in middle latitudes under these same conditions. Therefore, the ice-crystal mechanism cannot be the only important cause of raindrop formation.

The other important mechanism of coalesence is now thought to be collision

---

3. "Physics of the Air", by W. J. Humphreys, 3 ed., p. 276, McGraw-Hill, New York, 1940.
4. "On the Physics of Cloud and Precipitation", by Tor Bergeron, Trans. Int. Union of Geodesy and Geophysics, pt. 2, pp. 156-178, 1935.

of cloud elements. The probability of collision is quite small for the tiny cloud elements but as they grow in size their projected area increases and with it the likelihood of collision. Moreover, the fall velocity of drops increases with drop diameter so that the relative velocity of the large drops with respect to the smaller drops permits the large drops to overtake and collect the smaller ones. If a cloud is very shallow, the chances that a drop falling through it will grow large enough to fall as precipitation are not great. On the other hand if a cloud is many thousands of feet in height, a drop will have a good chance of growing to the necessary size. Storm clouds in tropical regions often extend to very high levels and coalesence by collision seems to be a reasonable explanation for precipitation from such clouds. In middle latitudes, clouds rarely attain the vertical extent common of tropical clouds and collision alone seems hardly adequate to explain more than occasional moderate rainfall. If, however, the ice-crystal process can promote the initial growth of drops to some intermediate size, the collision process might complete the job. Thus, the present-day concept of the growth of cloud droplets to precipitation elements visualizes the ice-crystal effect as providing the initial impetus and the collision process as bringing about the final growth of the droplets[5]. This does not mean, however, that either process alone may not be responsible for the formation of precipitation elements under some conditions.

Condensation and Sublimation

The previous discussion developed the conclusion that the formation of precipitation requires either (1) coexistence of ice and water drops or (2) presence of a substantial range of drop sizes within a cloud. Condensation of water drops takes place on condensation nuclei. These nuclei are present in large numbers in the atmosphere. A summary of a large number of nuclei counts by Landsberg[6] showed an average of 940 nuclei per cc over the ocean and 147,000 nuclei per cc near large cities. Condensation nuclei consist of particles formed during combustion, dust, soil particles, and crystals of sea salt. The salt particles, while relatively few in number, seem to be larger than most other nuclei. It has been suggested that salt particles may often provide the large drops necessary to bring about precipitation in coastal areas.

After Bergeron's theory was first presented it was assumed that the ice crystals form directly by sublimation on suitable nuclei. Investigators have found it difficult to isolate such sublimation nuclei. Some workers have concluded that true sublimation nuclei do not exist and that ice crystals form by freezing of water droplets. This freezing does not take place at the ordinary freezing point, 32° F. Supercooled liquid water has been observed at temperatures as low as -60° F and the spontaneous freezing point has been computed from theoretical arguments as about -90° F. Various nuclei seem to posses a specific critical temperature at which freezing of the enveloping water drop begins. A few natural nuclei seem to have critical temperatures as high as 0° F, but most ice crystal formation seems to occur at about -40° F under natural conditions. Nuclei upon which freezing of the water occurs are not as abundant as are the condensation nuclei. Often less than one freezing nucleus is observed in each cc of an air sample. It is possible, however, that the ice

---

5. "A Preliminary Quantitative Analysis of Precipitation Mechanisms", by Henry G. Houghton, Journal of Meteorology, Vol. 7, pp. 363-369, 1950.
6. "Atmospheric Condensation Nuclei," by H. Landsberg, Beitrag zur Geophysik, Supp. 3, pp. 155-252, 1938.

crystals formed by the freezing of the water drops may fracture into tiny splinters of ice which serve as true sublimation nuclei.

The scarcity of freezing nuclei and the low temperatures at which they become effective are the strong arguments in favor of artificial nucleation of clouds to increase precipitation. If the air temperature at the ground is 70° F a cloud would have to extend above an alititude of 30,000 ft to reach the level at which temperature was -40° F. Many clouds do not reach such heights. Even if a cloud is sufficiently supercooled to bring about natural nucleation of ice crystals, it is conceivable that the number of natural nuclei would be insufficient to produce heavy rain. The feasibility of inducing nucleation at air temperatures above -40° F was demonstrated by Schaefer[7] in a cold chamber consisting of a home freezer with its inner walls lined with black cloth to improve visibility. Supercooled water drops can be formed in such a chamber by exhaling breath into it. Schaefer found that anything which cooled the droplets below -40° F resulted in formation of ice crystals which appeared as twinkling stars in a light beam through the chamber. Such cooling could be accomplished by using dry ice (temperature -108° F) or any object cooled in dry ice. This was demonstrated in nature by seeding a layer of stratus clouds near Pittsfield, Mass. in November, 1946. The clouds along the seeding track were dissipated, and a line of snow streamers was observed falling toward the ground.

Vonnegut[8], searching for other substances which might also serve as nuclei, concluded that silver iodide would be effective because its crystal structure is quite similar to that of ice. Field and laboratory tests confirmed this conclusion. Water droplets which are supercooled to 30° F can be transformed to ice crystals by use of dry ice (or any other material with a very low temperature), while silver iodide nuclei have a threshold temperature of about 25° F. Either of these agents can bring about the formation of ice crystals in clouds which are far below the levels required for natural ice-crystal formation. It has also been found that a spray of water drops in the top of a warm cloud may bring about precipitation by providing a few large drops necessary to make the collision mechanism effective.

Physical Evaluation of Factors Affecting Cloud Seeding

In view of the uncertainty as to the relative importance of the various mechanisms for the coalesence of cloud droplets into precipitation elements, it is difficult to make a quantitative evaluation of the potential value of cloud seeding from the physical viewpoint. There are some aspects of the precipitation process and of the conventional methods of cloud seeding which should be considered.

Moisture Supply.—A mechanism for the formation of precipitation elements is not the sole requirement for the occurrence of heavy precipitation. There must also be an adequate quantity of moisture available. One gram of water per cubic meter (0.002 cu in. per cu ft) is a relatively high water content for cloud. If all of the moisture in a cloud 10,000 ft thick and containing one gram of moisture per cubic meter were precipitated, only about 0.15 inches of rainfall would result. Actually not all of the moisture could be precipitated

7. "The Production of Ice Crystals in a Cloud of Supercooled Water Droplets," by V. J. Schaefer, Science, Vol. 104, pp. 457-459, 1946.
8. "The Nucleation of Ice Formation by Silver Iodide", by B. Vonnegut, Jour. App. Phys., Vol. 18, pp. 593-595, 1947.

and some would reevaporate before it reached the ground.

Clearly, a second requirement for the occurrence of heavy precipitation is a continuing circulation of air which brings additional moisture into the cloud to refuel the precipitation process. Without such a circulation precipitation, either natural or artificially induced, will be light and of short duration and will be accompanied by dissipation of the cloud. A strong movement of air against a mountain or a frontal barrier results in a large upward component of movement which helps to carry the air up to levels where natural ice-crystal formation may occur. Strong lateral inflow at the base of a thunderstorm must be accompanied by powerful updrafts which encourage vertical growth of the cloud to levels where natural drop formation is favored. Hence, the requirement of a substantial inflow of moisture which is equally necessary for either natural or artificial precipitation, creates conditions which favor the occurrence of natural precipitation. It may be concluded therefore that artificial nucleation can be effective only in marginal cases where natural precipitation-forming mechanisms are not quite effective. In many cases seeding of clouds may do little more than advance the onset of rain by a few minutes or a few hours. If the precipitation elements are caused to form at lower levels as a result of artificial seeding, the vertical development of the cloud and consequently its total water content may be reduced.

Overseeding.—The ice-crystal theory of precipitation formation requires that the number of ice crystals in a cloud be relatively small in comparison to the number of water droplets present. Since each drop must grow in size by 125,000 times or more, one ice crystal for each 125,000 water drops would be a reasonable proportion. If there are too many ice crystals, only a few will be able to grow to a size sufficient to cause precipitation. If natural rain is in progress some natural nuclei must be present and the addition of artificial nuclei might result in too many nuclei or overseeding. Actually, overseeding has been deliberately employed in attempts to prevent precipitation and to dissipate thunderstorms to avoid hail or lightning. In any particular case it is virtually impossible to determine the concentration of natural nuclei to estimate the number of artificial nuclei which should be supplied for best results. The problem is made more difficult by the fact that a gram of dry ice will produce some 10^{16} ice crystals under favorable conditions[9]. Thus a single pellet might conceivably nucleate a cubic mile of cloud with 10^5 nuclei per cubic foot. It is evidently difficult to distribute the seeding agent in quantities small enough to avoid the possibility of overseeding.

Seeding from the Ground.—Seeding of clouds from aircraft during major storms is an expensive and perhaps even a dangerous operation. Hence, the most widely used seeding technique today is to create silver iodide nuclei by burning an acetone solution of silver iodide with butane gas. The nuclei thus produced are supposed to rise from the ground generator to the proper level in the cloud. This type of operation is susceptible to several difficulties. If an inversion exists the silver iodide may not rise above the inversion level. Inversions will be familiar to many readers as the ceilings which trap smoke and dust to create smog in metropolitan areas. Actually an inversion is a situation in which warmer air overlies colder air, and the lower and colder air cannot rise through the warmer air. A weather front (Fig. 1) is a surface

9. "The Production of Clouds Containing Supercooled Water Droplets or Ice Crystals under Laboratory Conditions," by V. J. Schaefer, Bull. Amer. Meteorological Soc., Vol. 29, pp. 175-182, 1948.

(or more properly a zone) where warm moist air is lifted above colder air. A front is thus an inversion and it is quite possible that silver iodide released in advance of a warm front may never reach the freezing level.

A second problem created by use of ground generators is that of aiming for a selected target. The exact shape of the plume of silver iodide nuclei produced by the generator is not known and no doubt this plume varies from day to day just as the smoke plume from a chimney takes differing shapes under differing weather conditions. However, the nuclei must certainly drift with the wind as they rise. The raindrops also drift with the wind as they fall. Since upper air wind speed usually varies with altitude, the trajectory of the nuclei and the drops may be quite complex. The generator must be placed sufficiently to the windward of the target area (Fig. 2) so that the precipitation resulting will strike the target. This is obviously rather difficult to plan and it is quite possible that the effects of cloud seeding are often felt in some area quite removed from the intended target.

Silver iodide, like the silver salts used in photographic processes, is photolytic. That is, the crystal structure of the silver iodide nuclei is changed by exposure to light[10]. Since silver iodide is an effective nucleating agent because of the similarity between its crystal structure and that of ice, the effect of photolysis is to diminish its nucleating properties. Various experiments have yielded somewhat different quantitative results concerning the magnitude of the photolytic deactivation. Certainly the intensity of the light and the duration of the exposure play an important part in the deactivation. Other experiments have indicated that the relative humidity is also an important factor in determining the rate of deactivation during exposure to light[11]. Photolytically deactivated nuclei apparently regain their effectiveness if treated with ammonia[12]. Ammonia treatment before deactivation does not seem to prevent the photolytic action although some seeding operators do mix ammonia with the silver iodide solution in the generator. The effect of the photolytic deactivation and the uncertainty as to the degree of dispersal of nuclei by wind make it difficult to judge the proper rates of generator operation while seeding.

Field Tests of Artificial Nucleation

The many unknown factors in the process of artificial nucleation make it difficult to reach any positive conclusions concerning potential economic benefits on the basis of physical analysis alone. It is only natural, therefore, that extensive field tests have been conducted in all parts of the world since the first demonstration by Langmuir and Schaefer in 1946. Field tests create a new problem, namely that of evaluating the effects of the seeding operation.

Numerous trials have been made by seeding thin layers of stratus clouds. The seeding runs are made in some distinctive pattern so that any resulting change in the cloud can be identified as a result of the seeding. These tests

10. "Photolytic Inactivation of Ice Forming Silver Iodide Nuclei" by E. C. Y. Inn, Bull. Amer. Meteorological Soc., Vol. 32, pp. 132-135, April, 1951.
11. "The Effect of Relative Humidity on the Nucleating Properties of Photolyzed Silver Iodide," by S. J. Birstein, Bull. Amer. Meteorological Society, Vol. 33, pp. 431-434, Dec., 1952.
12. "Effects of Sunlight and Ammonia on the Action of Silver Iodide Particles as Sublimation Nuclei," by S. E. Reynolds, William Hume, and Max McWhirter, Bull. Amer. Meteorological Society, Vol. 33, pp. 26-31, January, 1952.

have shown that it is quite possible to transform a water cloud to an ice crystal cloud. This transformation is usually accompanied by the dissipation of the cloud along the seeding track. It is possible that seeding may offer a means of improving visibility at airports under some conditions. Stratus cloud decks are usually rather shallow and as a result very little precipitation has been observed after seeding trials of such clouds. Streamers of precipitation were frequently observed beneath the clouds but amounts reaching the ground were usually very small.

Isolated cumulus clouds of the type which often result in summer thunderstorms offer another attractive target for field tests. It is possible to select an isolated cloud, seed it from an airplane, and observe the results either directly or with radar. If no other rain is occurring within the general area of the test, it can be assumed with some assurance that any rain falling from the seeded cloud was the result of the seeding. If rain is occurring at the time of the seeding or begins shortly after seeding from other clouds in the area some doubt as to the effect of the seeding exists. It is possible that in some cases the seeding merely brings on rain earlier than nature would have. There is no doubt that some time elapses between the beginning of natural nucleation and the onset of rainfall. This time lag consists of the time required for nucleation and the time for the drops to fall through the cloud and emerge from its base and may easily amount to 30 minutes or more. Use of ground generator equipment for seeding cumulus clouds complicates the problem of evaluation still further because of the uncertainty concerning the path of the silver iodide and the additional time lag while the silver iodide is reaching the cloud. Australian tests[13] of ground generators for seeding cumulus clouds indicated no success in producing added rain. Langmuir[14] on the other hand sees much success in experiments under his direction.

Seeding of cumulus clouds with dry ice seems to indicate that artificial nucleation can induce rainfall which would not have occurred naturally. However, not all seeding trials[15] produced rainfall and in most cases when rain was observed the amounts were quite small—generally under one-fourth inch. Only in a very small percentage of the tests was really heavy rainfall observed and in many of these cases the occurrence of rain from other clouds in the vicinity casts some doubt on the belief that the rain resulted from seeding. In many cases trails of rain were observed below the cloud but no precipitation reached the ground. The most frequent result of the many seeding tests on cumulus clouds has been the dissipation of the cloud without any important precipitation.

---

13. "Australian Experiments in Artificial Rainmaking", by E. G. Bowen, Bull. Amer. Meteorological Society, Vol. 33, pp. 244-246, June, 1952.
14. "Control of Precipitation from Cumulus Clouds by Various Seeding Techniques," by Irving Langmuir, Science, Vol. 112, pp. 35-41, July 14, 1950.
15. "Canadian Experiments on Artificially Inducing Precipitation" by J. L. Orr, D. Fraser, and K. G. Pettit, Bull. Amer. Meteorological Soc., Vol. 31, pp. 56-69, February, 1950.
"Experiments in Seeding Cumuliform Cloud Layers with Dry Ice" by E. J. Smith, Australian Jour. of Sci. Research, Series A, Vol. 2, pp. 78-91, March, 1949.
"Second Partial Report on the Artificial Production of Precipitation: Cumuliform Clouds, Ohio, 1948," by R. D. Coons, E. L. Jones, and Ross Gunn, U. S. Weather Bureau Research Paper No. 31, Washington, D. C., 1949 (Summary published in Bull. Amer. Meteorological Society, Vol. 29, pp. 544-546, December, 1948).

Tests of seeding techniques on isolated cumulus and thin stratus clouds have shown the feasibility of transforming cloud structure and of inducing rainfall artificially. These same tests confirm the fact that seeding of thin or isolated clouds cannot hope to produce precipitation of economic value except in very special cases. Another possible application of artificial nucleation methods is the seeding of large scale storms to increase rainfall over a large area. Since some natural rainfall is almost certain to occur during the passage of such storms, it is not possible to observe the effects of the seeding visually or with radar and some other method of evaluation must be used.

If it were possible to predict accurately the amount of precipitation which would occur at selected points during a storm, any departures from these predicted amounts might be attributed to the seeding. Such precise forecasts are not yet possible with the techniques now available to meteorologists. Hence, evaluation of the effects of cloud seeding on large storms must be accomplished statistically. The most common method is to compare the rainfall on the target area with the rainfall occurring in one or more nearby control areas which are presumed to be unaffected by the seeding operation. Unfortunately, even with natural conditions the precipitation amounts on the target and the control areas will not bear any precise relationship to one another. If the target and control areas are separated by large distances, the correlation between storm rainfalls on the two areas may be quite poor. A typical correlation plot is shown in Fig. 3. Note that in some instances the target stations have received relatively more precipitation than the control stations while in other storms the situation is reversed. Some of this variation can be explained by classifying the storms into types and analyzing each type separately. This yields several lines representing conditions for the various storm types on the basis of historical data, but the variation or scatter of points about each line is somewhat less than if all storms are grouped together. No technique has yet been found which will permit adjustment of the historical data in such a way that all storms conform exactly to a single curve.

Statisticians measure the scatter of data about a line such as that of Fig. 3 by the variance or standard deviation of the departures from the regression line. The variance, μ, is computed from the equation

$$\mu = \frac{(X - X')2}{N - 1} \qquad (1)$$

where X is an observed value of rainfall on the target area, X' is the corresponding value of rainfall for the target area as computed from the observed rainfall in the control areas, and N is the number of storms included in the analysis. The standard deviation, σ, is equal to $\sqrt{\mu}$. If the scatter of points about the regression line conforms to the normal distribution, about 68% of the points will fall within $\pm 1\sigma$ from the line, 95.5% will be within $\pm 2\sigma$, and 99.7% will be included within a range of $\pm 3\sigma$ from the line. Thus if a seeded storm were to fall more than 3σ above the line of Fig. 3, the probability that it is a natural occurrence is slight and the probability that seeding increased the precipitation is correspondingly high. On the other hand if the points representing seeded storms fall close to the mean line as is the case in Fig. 3, the probability that seeding was effective is rather low. In a like manner, if the seeded storm falls below the line, it is possible to compute the probability that the seeding actually reduced the rainfall in the target area by overseeding. The actual statistical tests involve numerous refinements which are necessarily omitted from this simplified discussion.

It is important to note that the statistical evaluation can do no more than indicate the probability or odds in favor of the success of a seeding trial. The

probability of success that is accepted as being reasonably convincing must be arbitrarily selected. Statisticians normally consider a probability of 0.95 as significant and 0.99 as highly significant. Thus if there is only 1 chance in 20 that the observed deviation from the relationship could have occurred naturally it is taken as a significant indication of the success of seeding, while a deviation which might have occurred naturally only once in 100 cases is considered as a highly significant indication of success in a seeding trial.

A considerable number of seeding trials have been evaluated by methods similar to the one just outlined. As far as the writer is aware, no evaluation by a group not directly interested in the seeding operation has found that seeding of large scale storms resulted in a significant increase in rainfall. In several instances the data seem to suggest that there may have been a decrease in rainfall as a result of the seeding. It must be noted that most of the tests which have been evaluated cover only a short period of time. If the effect of seeding is not large, it might not be readily detected on the basis of an analysis of a short seeding operation in which only a few storms are available for study. The results of statistical analyses to date should, therefore, be summarized as indicating that on the whole cloud seeders have not demonstrated any conclusive success but that possibly small increases (10% or less) may not be detectable with present data and analytical techniques. Most seeding of general storms has been done with silver iodide generators on the ground and is subject to the difficulties mentioned earlier. The results of some evaluations are summarized briefly in Table 1. Such a table cannot present all pertinent facts and readers are urged to read the full reports of these projects for details.

Another method which has been employed to evaluate the effects of artificial nucleation consists of seeding at regular intervals of time and attempting to detect a corresponding periodicity in weather. Project Cirrus[16] under the direction of Dr. Langmuir instituted a program of seeding at weekly intervals in New Mexico during late 1949 and 1950. Corresponding weekly periodicities in rainfall and other weather elements in the northeastern portion of the country were observed at times during 1950 and were attributed by Dr. Langmuir[17] to the seeding operations in New Mexico. Other writers[18] have found similar periodicities in weather elements in years prior to any seeding operations. It is therefore possible that the observed regularities in 1950 were natural and their apparent relation to seeding quite coincidental. Most readers will have doubtless observed certain regularities in the weather from time to time. It seems doubtful that periodic seeding offers any basis for conclusive tests of the influence of the seeding on precipitation and weather. It does not seem to provide any means of evaluating the quantitative effect of the seeding which is

---

16. "Project Cirrus: The Story of Cloud Seeding," General Electric Review, pp. 8-26, November, 1952.
17. "A Seven-day Periodicity in Weather in United States during April, 1950," by Irving Langmuir, Bull. Amer. Meteorological Society, Vol. 31, pp. 386-387, December, 1950.
18. "Seven-day Periods," by B. G. Holzman, Bull. Amer. Meteorological Society, Vol. 32, p. 113, March, 1951.
"On a Seven-day Periodicity," by William Lewis, Bull. Amer. Meteorological Society, Vol. 32, p. 192, May, 1951.
"On a Seven-day Periodicity in Weather in the United States during April, 1950," by E. Wahl, Bull. Amer. Meteorological Society, Vol. 32, p. 193, May, 1951.

necessary for any determination of the economic effects of artificial nucleation.

Hydrologic Evaluation of Cloud Seeding

Almost all efforts at evaluating the benefits of cloud seeding have been aimed at determining whether the seeding has increased precipitation. In a few instances[19] increases of stream-flow in streams of the target area have been the measure of the increased precipitation. Flow of streams in adjacent control areas serves as the basis of comparison for such analyses. A hydrologic evaluation of cloud seeding efforts should go farther than a determination of the net yield of runoff resulting from the seeding operation. It must also seek to determine what portion of any increase in precipitation or runoff was capable of being put to beneficial use and thus might have economic value.

Proponents of cloud seeding often compute the benefits of the seeding operation as the product of the precipitation increase over the entire target area expressed as a volume and the value of a unit volume of water. Thus for a target area of 1000 sq mi with a normal annual rainfall of 30 inches, a 10 per cent increase in precipitation would be computed as about 160,000 acre-feet (52,000 million gallons) which at a price of $3 per acre-foot would be worth about $480,000. If the seeding operation cost $30,000 the benefit-cost ration is apparently 16 to 1. Actually, however, in most areas only a fraction of any increase in rainfall would be useful.

From the viewpoint of the water works operator, only that water which reaches his reservoir has any potential value and this might be from one-fourth to one-third of the increase in precipitation on the tributary area. If the reservoir is full before the added flow occurs (or if subsequent natural runoff would have filled it) the increased runoff is wasted downstream and no benefits result. At the other extreme, under conditions of severe drought, the opportunity for seeding is slight and the benefits correspondingly low. Table 2 summarizes, for a hypothetical case, the benefits from ten consecutive years of seeding on a target area of 1000 sq mi, assuming a 10 per cent increase in rainfall, 25 per cent runoff from the increased rain and a reservoir capacity sufficient for runoff from the first 20 inches of rainfall. The net gain is 91,000 acre-feet which at $3 per acre-foot represents a return of $273,000 for an investment of $300,000. Of course the exact values will differ with the physical and meteorological characteristics of the target area, the value of water, and the facilities for storing and using the water. In some cases, the increased runoff will be added to flood flows and may, therefore, have a negative value equal to any added flood damage. In any case the actual benefits will be substantially less than those computed from the value of the gross increase in precipitation.

Irrigation projects and hydroelectric installations with reservoirs are in much the same position as the waterworks system with respect to the use of any increased precipitation. If no reservoirs are available for storage of the increased flows resulting from added rainfall then only that portion of the flow which is less than the demand at the diversion point (or the turbine requirements of a power plant) is useful. Farmers operating without benefit of irrigation benefit only from that rain which remains in the soil and is useful to plants. Thus the actual benefits of a seeding operation depend on the local

19. "Cloud Seeding in the Sierra near Bishop, California," by Ferguson Hall, T. J. Henderson, and S. A. Cundiff, Bull. Amer. Meteorological Soc., Vol. 34, pp. 111-116, Mar., 1953.
"Report on Bonneville Power Administration Cloud-seeding Operations," U. S. Dept. of Interior special report, July, 1952.

water situation and the facilities for using the water. These factors must therefore be evaluated in any study of the economics of cloud seeding along with the determination of the effect of the cloud seeding on the rainfall.

Legal Aspects of Seeding Clouds

A discussion of cloud seeding would not be complete without some mention of the legal problems involved. The writer is not a lawyer and does not propose to outline legal doctrine in this new and little explored field. The matter of water rights in surface and ground water is in itself a complex legal issue with differing laws and interpretations in every state. Many threats of lawsuit have been made as a result of cloud seeding operations. Unfortunately all of the people of an area do not agree on the need for precipitation. The grain farmer, forester, and water works operator may feel that added rain is essential. On the other hand the fruit rancher, construction men, and city folks on vacation may consider rain a decided detriment to their plans. Very few if any of the threats of suit have actually developed into trials. The writer has made no detailed survey of the problems, but it seems safe to assume that a major factor in preventing more active court cases has been the difficulty of proving the plaintiffs charges.

In general suits, or threats of suit, have taken two forms. In one form the plaintiff alleges that seeding of clouds to the windward of his area has taken from him water which he would have normally received. This might be viewed as an application of the riparian doctrine of water rights to atmospheric moisture. The assertion is that the leeward owner is entitled to the natural flow of moisture over his property undiminished in quantity. Huff and Stout in an analysis of the rainfall in Illinois found that six per cent or less of the atmospheric moisture was precipitated during a storm[20]. If seeding increases rainfall by as much as ten per cent it will remove less than one per cent additional moisture from the atmosphere. Thus the effect of seeding in depriving the leeward owner of atmospheric moisture is very slight. It is doubtful that a court would sustain a claim for damages where such a small percentage of the total moisture is involved. It is even more doubtful that the plaintiff could establish the amount of moisture lost to him.

The second type of suit involves a claim for damages alleged to be caused by increased or unnatural rainfall resulting from a seeding operation. Here a cause of action is more clearly evident but the difficulties of establishing the amount of the damages are considerable. The problem of proving that an increase in precipitation actually resulted from a seeding operation have already been discussed. No less difficult would be the problem of demonstrating the damages resulting from a given increase in the rainfall. Contractors who are influenced by rain as much as any other group would find it hard to prove the exact damage resulting from an additional 0.25 inch of rain added to a natural rainfall of two inches. Few people have their lives or their work so well ordered that small differences in the amount of the rainfall in a storm become important. One condition under which a clear cut issue might be established is that in which rain was caused by artificial means when no rain would have occurred naturally. Under these conditions the amount of precipitation will usually be quite small. However damage might result for the farmer who is drying fruit or hay, the farmer whose fruit is damaged on the tree, or the

20. "A Preliminary Study of Atmospheric-Moisture-Precipitation Relationships over Illinois," by F. A. Huff and G. E. Stout, Bull. Amer. Meteorological Soc., Vol. 32, pp. 295-297, 1951.

entrepreneur of an outdoor event—picnic, baseball game, or circus.

Another important legal aspect of rain-making is the question of governmental control. The Federal Government has as yet taken no action to regulate cloud-seeding operations in any way despite extensive discussion in Congress[21]. Many states now have laws requiring all seeding operations to be registered with some responsible authority and to be advertised publicly in advance of actual seeding. Some states also required that detailed reports of the seeding operations and the methods employed be filed with some public agency. In the writer's opinion all states should enact such legislation. The publicity attendant on such registration tends to suppress "quacks" who are trying to capitalize on the scientific basis of modern rain-making. In at least one instance the requirements of registration have disclosed that a secret seeding agent was nothing more than common salt. The registration also helps to make data available for analysis of the results of seeding, for legal action where justified, and for more intelligent planning of the seeding operation. Before the enactment of registration laws seeding operators often withheld data as a protection against lawsuits. Where registration laws are in effect, these data are now available for review and analysis by any interested and competent group. Likewise, before registration laws required advance advertising of a planned seeding project it was not uncommon for seeding to be conducted in areas so close together that interference could not be avoided and evaluation was made much more difficult.

Still another legal question connected with cloud seeding is the matter of contracts for seeding projects. Most engineers are accustomed to contracts which are governed by strict specifications of performance or product quality. Few such safeguards protect the purchaser of rainmaking services. Many contracts for cloud seeding are of the fixed-fee type in which the operator receives a predetermined sum for seeding at the times and by the methods he thinks best with no guarantee of results. In some cases a fixed-fee and bonus contract is used in which a certain sum is payable to the operator for services during a specified period and a bonus is payable only in event that the rainfall exceeds a certain quantity. In a few cases a performance contract has been used in which the operator received no pay unless the seeding increased the rainfall by a specified amount. Often performance contracts were used by seeding operators as a means of introducing themselves and their services, and the evaluation of the performance was made by the operator. In view of the difficulties of evaluation discussed earlier and the lack of personnel qualified to make an evaluation for the customer, it seems likely that many of the evaluations were exaggerated in favor of the seeding operators. Many seeding firms say quite frankly that artificial nucleation is still entirely experimental, yet the customer is expected to pay the full cost of this experimentation. These are conditions which would rarely be accepted by the customer if they were applied to some operation which he understood more thoroughly!

CONCLUSIONS

The following general conclusions may be drawn from the foregoing discussion.

1) A supercooled cloud may be at least partially transformed to ice crystals by seeding with dry ice. This transformation may be accompanied by

---

21. Joint Hearings before the subcommittees of the Committees on Interior and Insular Affairs, Interstate and Foreign Commerce, and Agriculture and Forestry, U. S. Senate, 82nd Congress, lst Session, 1951.

release of small amounts of rain from fairly deep clouds, or the dissipation of small cumulus and thin layer clouds.

2) Silver iodide is theoretically an effective seeding agent but experimental tests of seeding with silver iodide are less convincing than with dry ice. Among the reasons for less success with silver iodide may be the photolytic effect of sunlight, the lower critical temperature of silver iodide nuclei, and the problem of proper distribution of nuclei from ground generators.

3) Cloud seeding provides only a mechanism for the release of precipitation from existing clouds. The production of heavy rainfall requires the existence of a circulation which provides a continuing supply of moisture. The conditions favorable to successful cloud seeding are much the same as those required for the natural occurrence of rainfall.

4) Statistical studies by independent agencies have failed to show any significant increase in precipitation over a selected target area as the result of ground-based silver iodide seeding. Although it cannot yet be said that the seeding has no effect, it appears that any increases resulting from seeding have been very small.

5) The percentage of utilization of precipitation is an important factor in the economic evaluation of seeding operations and should be determined by hydrologic studies of the target area.

6) Seeding offers no relief from serious and prolonged drought, nor does it appear to offer a means for the modification of the weather of large areas.

7) State or Federal regulation of seeding operations through registration of seeding companies is desirable and necessary for intelligent evaluation of the results of cloud seeding.

8) Agencies considering the employment of cloud seeding should require a performance contract and demand that the seeding company provide the services of a competent meteorologist in the planning and execution of the contract. Companies using "secret agents" and refusing to discuss their seeding methods should be carefully investigated before employment.

BIBLIOGRAPHY

The following bibliography contains some general listings not utilized as specific references in the text, but useful to the reader who wishes to pursue the topic further.

"Bibliography on Artificial Precipitation," Meteorological Abstracts and Bibliography, Amer. Meteorological Soc., Mar., 1950.

"Problems in Rain Making," by T. H. Evans, Public Works, pp. 36-38, 76-78, July, 1951.

"Rainmaking—It worries Contractors," by R. K. Linsley, Western Construction, pp. 60-62, 140, March, 1953.

"Status of Possibilities of Artificial Precipitation," by Ferguson Hall, Trans. Amer. Geophys. Union, Vol. 33, pp. 866-870, Dec., 1952.

"Shaping the Law of Weather Control," Yale Law Journal, Vol. 58, pp. 213-244, January, 1949.

"Induced Precipitation and Experimental Meteorology," by V. J. Schaefer, Trans. New York Acad. Sci., Ser. II, Vol. 12, pp. 260-264, June, 1950.

"The Importance of Artificial Nucleation for the Production of Precipitation," by William Lewis, Trans. New York Acad. Sci., Ser. II, Vol. 12, pp. 264-267, June, 1950.

"Statement of the Council of the American Meteorological Society regarding artificial precipitation," Bull. Amer. Meteorological Soc., Vol. 34, pp. 218-219, May, 1953.

"An Appraisal of Cloud Seeding as a Means of Increasing Precipitation," by H. G. Houghton, Bull. Amer. Meteorological Soc., Vol. 32, pp. 39-46, Feb., 1951.

Cloud Physics," contributions by various authors to the Compendium of Meteorology, pp. 165-241, Amer. Meteorological Soc., 1951.

"On Methodology of Evaluating Cloud Seeding Operations," report of the Univ. of California Statistical Laboratory to the State of California Division of Water Resources, April, 1953.

TABLE 1 - SUMMARY OF SOME EVALUATIONS OF CLOUD SEEDING

Target Area	Evaluated by	Conclusion
Bishop Cr.,Calif.	Hall,Henderson, and Cundiff[a]	Possible increase of 9% in stream flow for three years.
Western Oregon	Beaumont[b]	Possible decrease in precipitation in target area.
Santa Clara County, California	Lieberman[c]	No significant effect on the precipitation for one year
Pend Oreille Basin, Washington	Special Federal Committee[d]	Slight increase in runoff in one of 3 seeded months.
Carrizo Plain, California	Scott[e]	Possible slight decrease in rainfall in target area.
Santa Barbara County,Calif.	Reynolds[f]	Possible slight increase in rainfall in one storm type.
North Central Colorado	Resnick[g]	No significant effect.
Central Arizona	MacCready[h]	Marked increase during one winter (1951)
	Brier & Enger[i]	No significant effect

a. See reference 19

b. See Bull. Amer. Meteorological Soc.,Vol. 34, p. 298, Sep.1953

c. See special mimeographed report, Stanford Univ. Statistics Laboratory, 1953

d. See reference 19

e. See mimeographed rept.,Univ. California Statistics Lab,1953

f. See mimeographed rept.,Calif.Div. of Water Resources, 1953

g. See mimeographed report, Colorado A & M College, July, 1951

h. See Bull.Amer.Meteorological Soc., Vol. 33, p. 48, Feb.,1952

i. See Bull. Amer. Meteorological Soc.,Vol. 33, p.208, May,1952

TABLE 2. CALCULATION OF LONG-TERM BENEFITS FROM CLOUD SEEDING

Year	Natural Rainfall (inches)	Increased Rainfall[a] (inches)	Increased Runoff[b] (ac-ft)	Usable Runoff[c] (ac-ft)
1	30	3.0	160,000	0
2	46	4.6	245,000	0
3	35	3.5	186,000	0
4	28	2.8	149,000	0
5	26	2.6	138,000	0
6	24	2.4	128,000	0
7	17	1.7	91,000	91,000
8	31	3.1	166,000	0
9	27	2.7	144,000	0
10	34	3.4	113,000	0
Total				91,000

a. 10% of natural rainfall

b. 0.25 x rainfall increase x 1000 sq.mi. x 640 x 1/12

c. any runoff from rainfall under 20 inches in a year

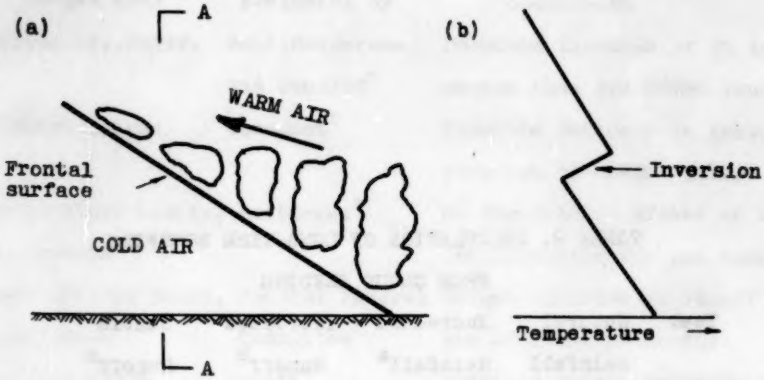

Figure 1.-- (a) Schematic cross-section through a typical warm front. (b) Vertical temperature profile at section AA showing inversion.

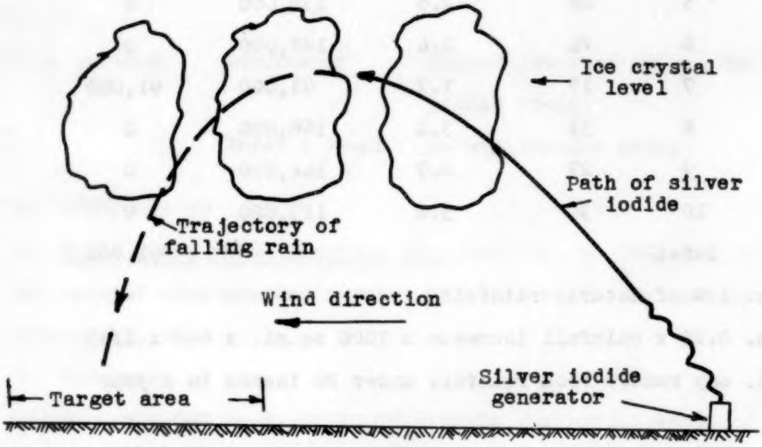

Figure 2. Schematic drawing illustrating placement of silver iodide generator to windward of target area.

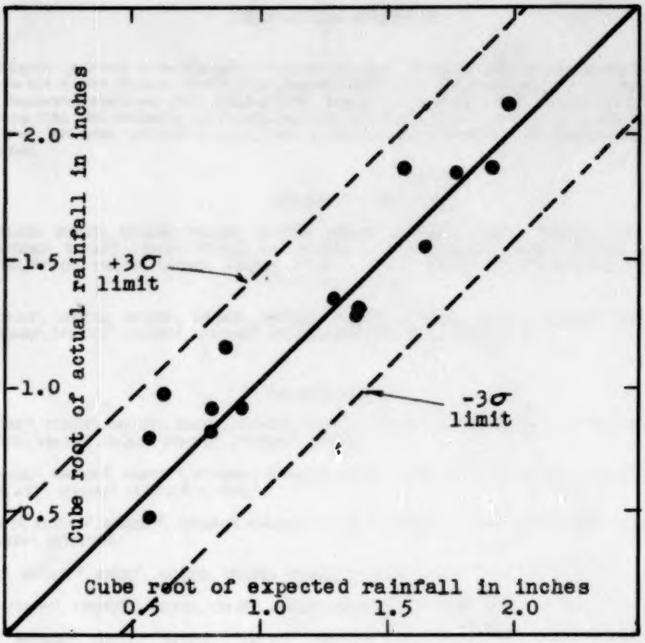

Figure 3. -- Comparison of actual rainfall in seeded storms with expected rainfall computed from regression between target and control area. Target area Santa Clara County, California during winter of 1951-52. Data from Lieberman.

PROCEEDINGS-SEPARATES

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

VOLUME 79 (1953)

NOVEMBER: 321(ST), 322(ST), 323(SM), 324(SM), 325(SM), 326(SM), 327(SM), 328(SM), 329(HW), 330(EM)[a], 331(EM)[a], 332(EM)[a], 333(EM)[c], 334(EM), 335(SA), 336(SA), 337(SA), 338(SA), 339(SA), 340(SA), 341(SA), 342(CO), 343(ST), 344(ST), 345(ST), 346(IR), 347(IR), 348(CO), 349(ST), 350(HW), 351(HW), 352(SA), 353(SU), 354(HY), 355(PO), 356(CO), 357(HW), 358(HY).

DECEMBER: 359(AT), 360(SM), 361(HY), 362(HY), 363(SM), 364(HY), 365(HY), 366(HY), 367(SU)[c], 368(WW)[c], 369(IR), 370(AT)[c], 371(SM)[c], 372(CO)[c], 373(ST)[c], 374(EM)[c], 375(EM), 376(EM), 377(SA)[c], 378(PO)[c].

VOLUME 80 (1954)

JANUARY: 379(SM)[c], 380(HY), 381(HY), 382(HY), 383(HY), 384(HY)[c], 385(SM), 386(SM), 387(EM), 388(SA), 389(SU)[c], 390(HY), 391(IR)[c], 392(SA), 393(SU), 394(AT), 395(SA)[c], 396(EM)[c], 397(ST)[c].

FEBRUARY: 398(IR)[d], 399(SA)[d], 400(CO)[d], 401(SM)[c], 402(AT)[d], 403(AT)[d], 404(IR)[d], 405(PO)[d], 406(AT)[d], 407(SU)[d], 408(SU)[d], 409(WW)[d], 410(AT)[d], 411(SA)[d], 412(PO)[d], 413(HY)[d].

MARCH: 414(WW)[d], 415(SU)[d], 416(SM)[d], 417(SM)[d], 418(AT)[d], 419(SA)[d], 420(SA)[d], 421(AT)[d], 422(SA)[d], 423(CP)[d], 424(AT)[d], 425(SM)[d], 426(IR)[d], 427(WW)[d].

APRIL: 428(HY)[c], 429(EM)[c], 430(ST), 431(HY), 432(HY), 433(HY), 434(ST).

MAY: 435(SM), 436(CP)[c], 437(HY)[c], 438(HY), 439(HY), 440(ST), 441(ST), 442(SA), 443(SA).

JUNE: 444(SM)[e], 445(SM)[e], 446(ST)[e], 447(ST)[e], 448(ST)[e], 449(ST)[e], 450(ST)[e], 451(ST)[e], 452(SA)[e], 453(SA)[e], 454(SA)[e], 455(SA)[e], 456(SM)[e].

JULY: 457(AT), 458(AT), 459(AT)[c], 460(IR), 461(IR), 462(IR), 463(IR)[c], 464(PO), 465(PO)[c].

AUGUST: 466(HY), 467(HY), 468(ST), 469(ST), 470(ST), 471(SA), 472(SA), 473(SA), 474(SA), 475(SM), 476(SM), 477(SM), 478(SM)[c], 479(HY)[c], 480(ST)[c], 481(SA)[c], 482(HY), 483(HY).

SEPTEMBER: 484(ST), 485(ST), 486(ST), 487(CP)[c], 488(ST)[c], 489(HY), 490(HY), 491(HY)[c], 492(SA), 493(SA), 494(SA), 495(SA), 496(SA), 497(SA), 498(SA), 499(HW), 500(HW), 501(HW)[c], 502(WW), 503(WW), 504(WW)[c], 505(CO), 506(CO)[c], 507(CP), 508(CP), 509(CP), 510(CP), 511(CP).

OCTOBER: 512(SM), 513(SM), 514(SM), 515(SM), 516(SM), 517(PO), 518(SM)[c], 519(IR), 520(IR), 521(IR), 522(IR)[c], 523(AT)[c], 524(SU), 525(SU)[c], 526(EM), 527(EM), 528(EM), 529(EM), 530(EM)[c], 531(EM), 532(EM)[c], 533(PO).

NOVEMBER: 534(HY), 535(HY), 536(HY), 537(HY), 538(HY)[c], 539(ST), 540(ST), 541(ST), 542(ST), 543(ST), 544(ST), 545(SA), 546(SA), 547(SA), 548(SM), 549(SM), 550(SM), 551(SM), 552(SA), 553(SM)[c], 554(SA), 555(SA), 556(SA), 557(SA).

---

a. Presented at the New York (N.Y.) Convention of the Society in October, 1953.
c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.